2016-12-30

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10.1007/s12371-016-0210-3
Geoheritage
Springer Science and Business Media LLC

The importance of geosites and heritage stones in cities – a review

by

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Abstract

Geology, as a scientific discipline, is often viewed as most applicable in high mountains or in deserts or coastal areas - or more generally in 'natural areas' where rock exposures are most conspicuous – and, therefore, not to be experienced by most visitors and tourists. In contrast, most geoscientists are convinced that geology can be practiced on an everyday basis, as it is part of our daily life as a facet of the natural environment that humans have used for 100s of 1000s of years. Even in places where the natural world seems far from its original condition, one can still experience geology. This consideration is of increasing importance as today, more than half the world's population lives in towns and cities. In this context, we can still present geology to an interested public, through establishing leisure walks, either guided or using leaflets, easily carried booklets and even web 'apps'. The style chosen aims to be accessible to a broader public, but crucially, in a urban context, there should always be an aim to demonstrate the relationship between geology and society, as well as architecture and history. Indeed, the realization of many participants in such activities that building stones can belong to, and provide evidence of, both a natural and a build heritage can be a revelation.

Keywords

Geoheritage, geotourism, urban geology, heritage stones, geosites

Introduction

To many, geology is a subject most applicable to areas where rock exposures are most prominent, such as mountain, coasts and large natural open spaces such as deserts. In addition, geology is for most people, a discipline out of reach and accessible only to geologists, and hence disconnected from their everyday reality. This view can create barriers – almost as a sort of self-protection from this supposedly inaccessible science – and many people do not admit to an interest in geology, hence abandoning this mysterious 'dry' topic to specialists. They are convinced that geology is not a part of their daily life – a feeling probably strengthened by the fact that today, half of the world's population lives in the artificial environment of towns and cities. Many geological themes suffer from this 'grey reputation, including its cultural, educational, and touristic aspects – and sometimes this attitude is not helped by geologists themselves. As stated by the English landscape historian, Professor W.G. Hoskins (https://en.wikipedia.org/wiki/William_George_Hoskins): "*Geologists have a habit of talking as dull and dusty as their rocks*".

Despite its history of secular development and knowledge-contribution to the scientific and technological development of modern society, geology still attracts little attention from people who fail to perceive the time dimension of slow processes and the transformation they cause on the planet (Clarke, 1991; Boulton, 2001; Mansur & Nascimento, 2007 ; Mondéjar, 2008). However, if they can read them, there are some visible signs that can help, such as the commemorative plate of Figure 1, whose bending shape attests that rock can fold within a few decades, not necessarily just over millions of years. The usual long timescales, however, are not easily appreciated, since most geological phenomenona seem to occur spectacularly abruptly, for instance volcanic eruptions, landslides, tsunamis and earthquakes. There is also still a predominant view that geology is a science mainly related to the search for oil and minerals for the economic development of a country. It is also sometimes linked to pollution of the planet: as a well-known Earth-photographer once observed at a meeting during the 'International Year of Planet Earth' declared that geologists are responsible for all types of pollutants - heavy metals in soils, oil slicks, roads and raised levels of CO_2 in the air – whilst ignoring that his plane was flying because all these gas, metals and plastics –which also made up his cameras

Fig. 1. A commemorative plate on the Observatoire de Paris (14e arrondissement), fixed in 1672 at the time of the inaugural ceremony, but now distorting due to surface weathering processes. "Observatoire construit de 1667-1672 sur les plans de Claude Perrault[1], membre de l'Académie des sciences" The wall is comprises Lutetian limestone (Eocene) and is full of the molds of molluscan shells. © P. De Wever

Some other examples can be find on walls of buildings telling that limestones are made of fossils, usually microscopic. However, one of the most incredible piece probably is the skull of a white shark of 5-6 meters long (a Lamniform, probably of Cretaceous age), which is clearly visible but almost ignored, and geologists do not dare to underline this important skull which could be carved out in a night (the reason why we do not provide here neither the address nor the name of the town, only that it is in France (fig. 2)

[1] Claude Perrault, is the brother of the Charles Perrault, a famous French author who laid the foundations for a new literary genre, the fairy tale (*Le Petit Chaperon Rouge* (*Little Red Riding Hood*), *Cendrillon* (*Cinderella*), *Le Chat Botté* (*Puss in Boots*), *La Belle au bois Dormant* (*The Sleeping Beauty*), and *Barbe Bleue* (*Bluebeard*).

Figure 2 : A stone with the skull of a shark used for facing a house
In a street of this town in France (we do not provide its name purposely) a pink Mesozoic limestone from Ravenne is visible. Being ignored nobody try to steal it.
The detail of the left part of the skull show the quality of the preservation. © P. De Wever)

Internationally, the geological content of national curricular has often been significantly reduced in both primary and secondary schools and, in consequence, many people have a very limited knowledge of the subject, confirming its inaccessibility. Although attempts at improving this situation have been made, including through international projects such as ‘Geoschools’ (geoschools.geol.uoa.gr; Fermeli et al. 2015) and even proposals for an international Geoscience school syllabus (King, 2015), much work still has to be done to improve the background to geological education in schools. This is why most laypersons are unprepared for the interconnected world of the Earth system operating at all space and time dimensions (Stewart and Nield, 2013).

This reputation also often impacts news and broadcast media and, therefore, only a limited collaboration with geoscientists exists, limiting diffusion of this science. But one has also to admit that the geological community globally often shows little interest in popularizing its subject - not a new phenomena as indicated by the Hosking’s quote used above… However, it only requires a slightly closer look to realise just how geological matters are present in all people’s lives, whether in the planning and occupation of towns and cities, in construction of roads and buildings, or in their leisure activities.

The UNESCO convention concerning the Protection of World Heritage of 1972 states that it is not possible to separate natural from built heritage – although in the context of towns and cities where cultural heritage is prominent, the natural aspects of the same heritage is often forgotten, with only a few examples of the promotion of 'Urban geology' being notable (but including the 1996 volume 'Geology on your Doorstep' (Bennett et al. 1996) and the work of the London Geodiversity Forum (http://www.londongeopartnership.org.uk/downloads/LGAP%202014-2018.pdf)).

The aim of this paper is to demonstrate how the importance of this natural heritage reflected in the sites and the natural stones used for building towns and cities can be presented, using as a primary example Paris, a vast urban location, but where Geology is easily available to a large audience in the shape of geoheritage.

Underground urban geosites

The sites of all towns and cities were initially parts of a 'pure' nature, but with settlement, successive inhabitants have adapted and exploited natural resources, including rocks and other geological deposits to build shelters, houses, or even palaces. As a consequence, urban sites range from areas retaining some of their original geological characteristics, such as natural or manmade outcrops (e.g. quarries) to architectural and sculptural complexes and streets. When stones were not available, or the accessible resource was soon quarried away, mines and caverns were often created, effectively underground quarries. Examples of such underground urban geosites are quite abundant in some towns. Under Paris, for example, an estimated 280-300 km of underground tunnels and quarries are known at different levels, excavated for working different materials, mainly limestones and gypsum. As a result, Paris is a like a 'Gruyere cheese' and it is not surprising that almost every year, there are instances of street collapse.

The Romans were the first to extract stones to build Lutetia, their proto-Paris. They began to excavate the Montagne Sainte-Geneviève (in the 5th district, where the Pantheon is now) along the valley of the *Bièvre*, a tributary of the river Seine, to obtain a good limestone for construction - the Lutetian (Eocene) 'calcaire grossier' - continued southwards (fig. 03).

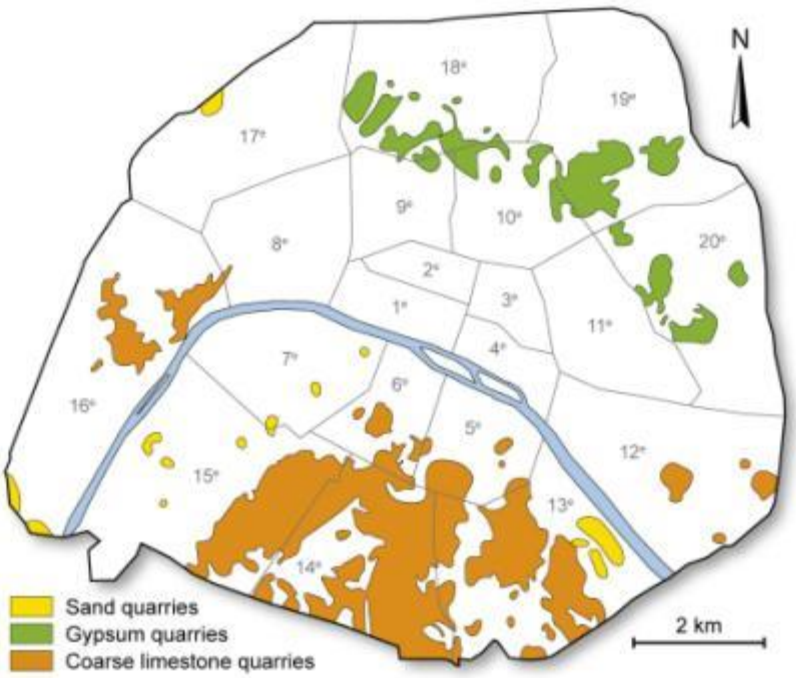

Fig. 03 Map of Paris' underground mine exploitations.
The orange areas (to the south) are limestone quarries, green ones (to the north) are gypsum.

Some of the best known remains of these workings are the 'catacombs' (in reality ossuaries) and the *Musée du Vin*, which provide good exposures of Lutetian limestones, and small geological exhibits have now been added. In other locations old quarrying tools are exhibited (fig. 04). Several of these underground quarries were once used to grow the mushroom *Agaricus bisporus* (J. E. Lange) which became known as the 'Champignon de Paris'.

Fig. 04- Underground quarries below Cochin hospital, Paris. The pillars, bed rock and tools bear witnesses to the work used to extract these stones for building Paris. © P. De Wever

By the end of the 19th century, quarries below the Museum National d'Histoire Naturelle, were being used by the zoologist, Pr. Armand Viré, as a biospeleological laboratory to study the adaptation of various organisms (insects, batrachians, etc) to darkness. His intention was to show the influence of darkness upon surface living forms and, in contrast, the action of light on cavernicoles. The laboratory was used until the First World War, when Armand Viré was conscripted into the army (fig. 05).

To the north of Paris (18th, 19th and 20th arrondissements and Seine Saint Denis), the upper Eocene (Ludian Stage) gypsum was extracted to make plaster (the famous 'plaster of Paris'). Some old underground quarries also survive, some with high vault-like, ribbed roofs, evoking the structure of cathedrals (fig. 06).

Similar underground mines are widespread across Europe. One very well studied case is the underground mining under Brussels, where the Lede Formation (shallow-marine limestone and sandstone deposited during the Eocene) has been actively exploited since the Middle Ages. Lede stone has been proposed as a candidate for nomination as a Global Heritage Stone Resource (GHSR) (De Kock et at. 2015), which adds an extra value to these sites. These underground workings are mainly known through old manuscripts, although sometimes major modern constructions have thrown more light on these historical cavities (Camerman 1955a,b). Devleeschouwer and Pouriel (2006) designed a 2D and 3D model for the underground workings to serve as an educational resource, but also for stakeholders connected with urban development and underground transport in the city. Other towns and cities have similar stories, including, although for many others, such as the remarkable 18th century planned townscape-construction of Middle Jurassic (Bathonian) limestones of the World Heritage city of Bath, south-west England, the extensive underground mines remained largely outside of the city limits, and some are still exploitated, in particular for restoration work (Perkins et al., 1979; Devon et al., 2001).

Not all underground excavations in towns and cities, however, were sources of building stone, others were dug simply for underground storage or refuge. Notable amongst those in England are the excellent exposures of Triassic sandstones ('Buntsandstein' equivalents) in former storage cellars incorporated England's oldest inn, the Ye Olde Trip to Jerusalem (1189) nestled beneath the rocky crags on upon which are the remains of the famous Nottingham Castle of the Robin Hood legend.

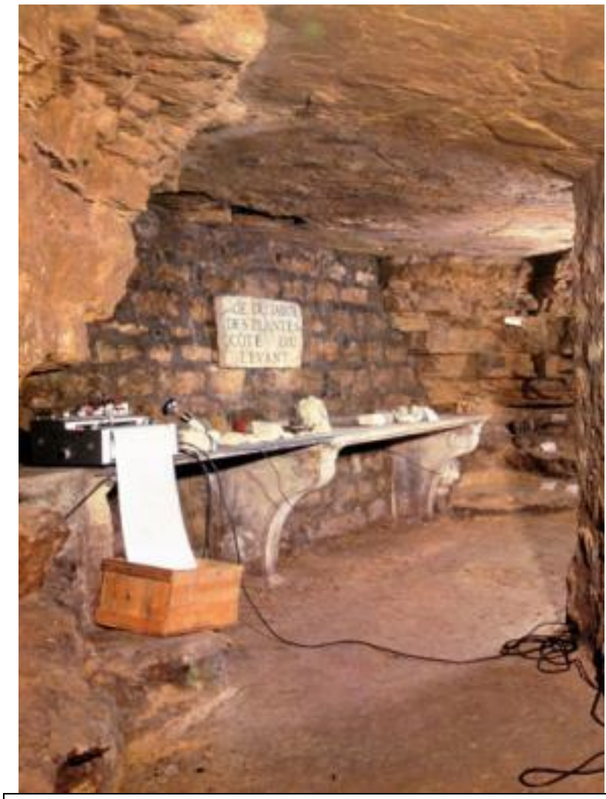

Fig. 05- A view of the biospeleogical laboratory under the Muséum. The white plaque on the wall locates the laboratory with respect to the surface: "Rue du Jardin des Plantes, côté du levant" (Jardin des Plantes street, east side). The carved table is made of Cararre marble. ©DR

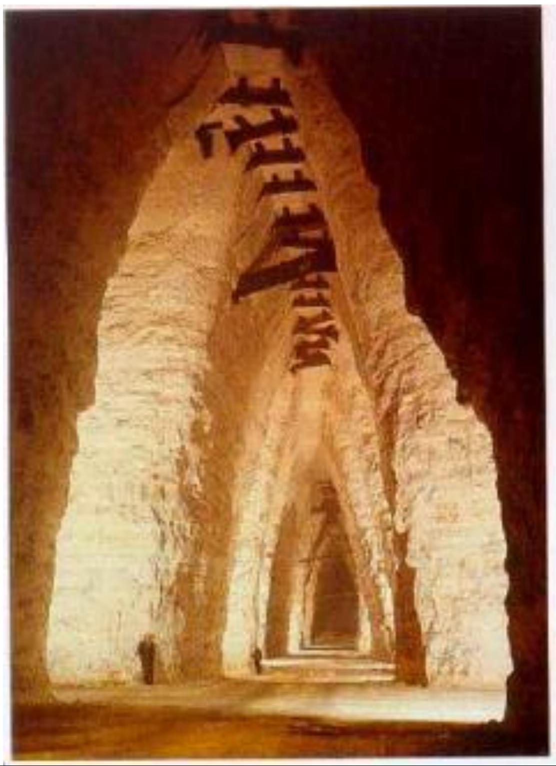

Fig. 06- Gypsum quarry below Livry-Gargan (Seine-Saint-Denis). These galleries reach a height of around 20 m © DR

Urban surface geosites

Historical buildings in European towns were usually built using the easiest available stones. Sometimes those stones were from the area of the same city (e.g. Nespereira et al 2010) or close to the city (e.g. Pereira et al. 2015; also Bath, as noted above). Some of these historical quarries may become historical sites for their strategic position as is the case of the Salamanca sandstone, quarried in the Los Arapiles, hills outside the city that were witnesses of the Independence War in 1812 (Pereira and González Neila, 2015) and may consequently acquire cultural designations or significance in their own right. In England, important stone mines such as those in the Middle Jurassic (Bathonian) near Bath, also became important at times of war, acquiring use as storage areas for munitions and even as secure underground 'bunkers' during the second world war (Perkins et al., 1979).

Extraction of stone to build massive buildings such as the cathedral of Notre-Dame de Paris resulted in the exhaustion of open quarries that had to extend laterally, southwardly, even when the topographic surface was elevating. Then they began to dig and todays some scares are still visible (fig. 07). When the topography was still elevating, there was too much overlaying terranes to take off, so the open quarry progressively became an underground gallery (as we have see on fig. 04, 05). This was also very much the case in many southern and eastern English examples, especially where the need for a hard stone for the construction of monumental buildings, for instance in areas dominated by relative soft Mesozoic to Quaternary deposits, meant that it was economically viable to start mining. Examples where surface quarries became extensive underground workings include the Beer Stone mines (Upper Cretaceous, Turonian) of east Devon which became important for the medieval construction of the City of Exeter (Dove, 1994) and medieval workings of Portland Stone in the Vale of Wardour, Wiltshire (Upper Jurassic, Tithonian) and the Isle of Purbeck, Dorset – both used to construct World Heritage buildings (including Salisbury cathedral in the former case), but curiously not included with the established GHSR for Portland Stone which focusses on the *geological* type locality of the Isle of Portland, also in Dorset.

In more northerly and western areas of Britain, i.e. with a older and harder Palaeozoic bedrock, it was not necessary to 'import' the stone from long distances, and traces of the quarries that yielded the materials of which the cities were constructed can often still be discerned amongst the buildings and in open spaces. Some of the most notable of these are those amongst Carboniferous igneous rocks in Edinburgh, Scotland, which benefited from one of the first conservation-linked legal decisions in the UK in 1831 (Cleal and Warren 2008**).** In the first 'Urban' Global Geopark in Torbay, Devon, SW England, first declared as a European Geopark in 2007 (www.englishrivierageopark.org.uk) this relationship if often very obvious, with former quarry faces in Devonian limestones being conspicuous wherever the limestone outcrops, but now surrounded by, and even filled with, houses and other buildings constructed from the same limestones. Indeed, quarrying was so intensive, that virtually none of the orginal limestone *Tors* that once characterized the *Bay*, survives today.

Fig. 07- : The “Jardin alpin” : an old quarry in the center of Paris
This area of the Jardin des Plantes (Muséum National d’Histoire Naturelle) is devoted to plants living on hard rocks and appropriate named. It corresponds to an old quarry in Lutetian limestones (Eocene) – the old quarry face is to the left. © De Wever

Returning to Paris, northwards, one can find gypsum quarries such as in the Buttes-Chaumont. The name of this park is tied to geology, as it takes its name from the bleak hill which occupied the site, which, because of the chemical composition of its soil, was almost bare of vegetation- hence ‘*Chauve-mont’*, or bare hill, which became Chaumont by contraction. This area, just outside the limits of Paris until the mid-19th century, had a sinister reputation as it was close to the site of the Gibbet of Montfaucon, the notorious place where the bodies of hanged criminals were displayed after their executions from the 13th century until 1760. The site is a former gypsum quarry which yielded Eocene mammal fossils, including *Palaeotherium*, (Fig. 08) which were studied by Georges Cuvier (see also Table 01) . The most famous feature of the park is the *Temple de la Sibylle*, a miniature version of the famous ancient Roman Temple of Vesta in Tivoli, Italy - which also inspired similar architectural follies in the English landscape gardens of the 18th century.

Fig. 08 The lower jaw of a *Palaeotherium* from Buttes-Chaumont studied by Georges Cuvier, as seen at the entrance of the Bâtiment de Géologie (Museum National d'Histoire Naturelle, Paris)© P. De Wever

Fig. 08 Ancient quarries of gypsum at Buttes-Chaumont, now a public park in north-eastern Paris. The 19th *arrondissement*, the Sybille's temple was built on gypsum © Egoroff G.

Elsewhere in Paris, other outcrops are visible in old quarries or underground, however, in areas of harder bed-rock geology some other towns (such as Brest : Jonin & Chauris, 2012; La Rochelle : Moreau, 2008 and Niort : Branger, 2012 in western France,;;) and Edinburgh and Nottingham, as noted above, natural outcrops remarkable remain. In many southern European areas, these outcrops can be spectacular, such as at Bonifacio in Corsica, where the old town is built on a promontory (Orsini et al., 2015, fig. 10). This stone, known as the 'Pierre de Bonifacio, was also used to build the town and is Miocene in age. Similarly in Porto, also in Corsica, red granite is part of the whole landscape (Gauthier, 1992, fig. 11) and it was used in construction World Heritage city.

Fig. 10- Bonifacio.
The old part of Bonifacio (Corsica), built on Miocene calcarenites. © Archives de l'Office municipal de tourisme de Bonifacio.

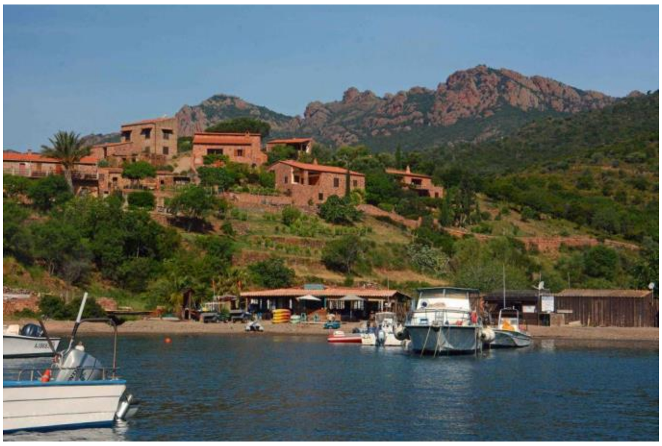

Figure 11 "Rouge de Porto" granite in the village of Girolata, an isolated village (no road for access) in the center of the Scandola reserve, a UNESCO World Heritage Site Porto-Ota (Corsica). The bed rock and traditional houses shows the same red color due to rhyolitic volcanism of Permian age © P. De Wever

Besides the rocks which are visible in situ, a great variety of other ones are accessible in towns either on buildings or on pavement or on curbstones. These rocks are usually more diversified than those found in situ, having been brought from many sources as reported by Billet et al., (2008), Obert et al., (2012a, b) for Paris, France, Borghi et al. (2014) for Turin, Italy, Del Lama et al. (2015), for São Paulo, Brazil and von Gnielinski and Siemon (2012) for Brisbane, Australia. Nevertheless, as discussed below, this variety can become an important resource for education, in its own right by providing a much more varied selection of rock types for study.

As well as obvious geological features and materials, some references to the geosciences in towns and cities can be more subtle, and survive only as place names. For instance old street names often evoke a physical or practical character of the area, for instance, rue des sablons ('fine sand street'), rue du plâtre ('plaster street'), while others may be dedicated to some local or national celebrity, who may or may not have had a specific connection with the locations. In Paris, a significant number are dedicated to geoscientists (table 01).

Name	**Arrondissement**	
Beudant (François-SulpiceBeudant, 1787-1850)	XVIIe	Mineralogist
Biot (Jean-Baptiste Biot, 1774-1862)	XVIIe	Geochemist for meteorites, patronym of the biotite
Brongniart Alexandre (1770-1847)	XVIIe	Geologist
Buffon (Georges-Louis Leclerc, comte de Buffon, 1707-1788)	Ve	Naturalist
Cassini ?		
Copernic ?		
Cuvier (Georges Cuvier, 1769-1832)		Palaeontologist
Darcy (Henry Darcy, 1803-1858)	XXe	hydrogeologist
Darwin (Charles Darwin, 1809-1882)	XXVIIIe	Biologist, Palaeontologist,
Daubenton (Louis Jean Marie, 1716-1800)	Ve, Grave in the garden of the Museum	Mineralogist
Dolomieu (Déodat-Guy-Sylvain-Tancrède Gratet, marquis de Dolomieu, 1750-1801)	Ve	Mineralogist Patronym of Dolomie, dolomite, and Dolomites mountains, in Italy
Dufresnoy (Armand Petit-Dufesnoy (1792-1857)	XVIe	Mineralogist
Friedel (Charles friedel, 1832-1899)	XX	Chemist and mineralogist
Galilee ?		
Geoffroy-saint-Hilaire (Etienne Geoffroy, dit Saint-Hilaire, 1772-1844)	Ve	Palaeontologist
Haüy (René Just Haüy, 1743-1822)	XVe	Crystallographer
Jacquemont (Victor Jacquemont, 1801-1832)	XVIIe Grave in the building of the *Grande Gallerie de l'Evolution*, Muséum	Geologist, naturalist
Lamarck (Jean-Baptiste de Monet, chevalier de Lamarck, 1744-1829)	XVIII	Palaeontologist
Lapparent (Albert-Auguste Cochon de Lapparent, 1839-1908)	VIIe	Geologist
Lavoisier (Antoine-Laurent de Lavoisier, 1743-1794)	XVIIIe	Chemist and stratigrapher
Linné ?		
Meunier (StanislasMeunier, 1843-1925)	XXe	Geologist, meteorites
Milne-Edouard (Henri Milne-Edouard, 800-1885)	XVIIe	Zoologist, palaeontologist
Newton ?		
Palissy (Bernard palissy, 1510-1590)	VIe	Ceramist & palaeontologist
Saussure (Horace-Benedict de Saussure	XVIIe	Geologist
Teilhard de Chardin (Pierre Teilhard de Chardin,	Place, IV	Palaeontologist

Table 01 Street names honouring geoscientists in Paris

Heritage stones

<u>Heritage stones and history</u>

The link to local territory and thus to local geology is most pronounced for the oldest monuments. The maximum use was made of local materials, everything resembling a stone found at or near-surface was put to use, sometimes after allowing time for hardening, or even accelerating this natural process by using carbonated liquids and other 'consolidants'.

Churches generally have a very good representation of local geology, even if only the 'best' stones were used. Notre-Dame de Paris is constructed with different types of Lutetian limestones, the usage of each depending on the location in the building (e.g. miliolid limestone for statues, microbial and algal limestone for lower areas), with other French examples including Strasbourg cathedral which is made of a Triassic red sandstone, Autun cathedral with a grey Lower Jurassic limestone rich in *Gryphea* and Clermont-Ferrand's cathedral is mainly made of Volvic stone (a trachy-andesite lava from Quaternary age, in the Central Massive). This pattern of usage is characteristic of older ecclesiastical buildings throughout Europe being representative of a regional geology, as generally they are amongst the oldest surviving buildings of high status in most towns and cities and the long distance transport of materials was expensive. Salisbury Cathedral in southern England, as noted previously, is another good example, where even in mediaeval times (from 1220 to around 1266; http://www.salisburycathedral.org.uk/) it was worth transporting high quality Portland (dimension) Stone around 18 kilometres for use in a high status construction.

The oldest and most modest buildings, however, are often constructed of the most local of building stones, and are often a clear testimony to the nature of the very local geology at such a point that it can be used to spot some wine types (De Wever et al., 2010). This situation changed radically, however, as new methods of transportation were established. especially by barge on rivers and canals and later by train (Cailleaux 1997, Pomerol 2000, 2006 ; and Pereira and Cooper, 2014). For sophisticated buildings, of course, the cost being less of a constraint when the most suitable, or even fashionable stones where imported from distant places. In France the most spectacular change occurred with Louis XIV in the 17th century, most famously as he redeveloped the Versailles palace. For this ambitious construction, decorative and construction materials were sought from across Europe, including many from Pyrenees mountains bordering France and Spain, including Sarrancolin marble, or Sienne Brocatelle, Florence green marble (in fact a serpentinite) and the famous Carrare marble from Italy, and from the Ardennes massive, the 'Marbre rouge des Flandres' (also known as 'Rance's Stone') - a reefal limestone of Frasnien (Upper Devonian) age (Groessens, 1992, 2012; Tourneur and Pereira 2016)

More recently, during the 19th century, with the construction of the 'Canal de Bourgogne', a route for transporting stones from Burgundy opened up. As a result Paris and its surroundings were literally invaded by stones from this region, including many of Jurassic age such as the Oxfordian oolitic limestones (Calcaire d'Euville) and the very fine grained, pinkish Mid Jurassic Comblanchian limestone (see 'Stop 13' below and figs.17 and 18) A spectacular example is the main city hall of Paris: Originally build with Lutetian limestone (Fig. 11) during the reign of François Ist (16th century), but burnt during the Paris Commune in 1871, it was mainly rebuild with Jurassic oolitic limestone from Bourgogne in 19th century (Obert et al. 2015).

Fig. 11 : Lutetian limestone used for buildings: This example was used in the 'Grand amphithéâtre' of the Muséum National d'Histoire Naturelle in 1788. This rock is characterized by abundant moulds of gastropods (mainly ceriths) © P. De Wever

A very similar pattern of several generations of the use of different stone types can probably be found in most towns and cities, even where monumental architecture is not such a dominant part of the 'townscape'. An excellent example of this is the city of Exeter in the county of Devon in south-west England. Based on a pre-existing celtic settlement, when construction of Roman *Isca Dumnoniorum* began in around 55 AD, local Permian basic volcanic rocks – historical known as 'Exeter Traps' - were used (the site of quarrying survives in the centre of Exeter, although occupied by the much later 'Rougemont Castle'). The resource was limited, however, and by medieval times, the much inferior Heavitree Breccia, also of Permian age and quarried from the east side of the city, was being extensive used – window and door frames, however, were commonly still being constructed of 'Exeter Traps' (much, no doubt, recycled from earlier Roman use). The same is true for the remains of the city walls, which show a mixture of 'Traps', as used originally by the Romans, with later 'Breccia' additions are repairs (Dove 1994).

Meanwhile, new excavations and mines on the coast of East Devon in Cretaceous sandy limestone known as 'Salcombe Stone' (Albian) were providing better quality stones for facing walls, in particular for the rebuilding of Exeter Cathedral between 1270 and 1370 – again, the status of the building meaning that the long journey necessary, including around 28 km by sea and river was not significantly prohibitive factor. In addition, high quality Turonian 'Beer Stone', a pale limestone large composed of finely fragmented *Inoceramus* bivalve shells, from the same area was being used for door and window frames and statues – remarkably this stone had been worked since Roman Times and extensive underground mines now exist.

Although other stones arrived into Exeter later, such as Ham Hill Stone from Somerset for door and window frames (Toarcian, Lower Jurassic), Middle Devonian limestone from Torquay (south Devon) for whole buildings, Dartmoor granite (central Devon, Variscan) for kerbstones, it was the new railways that provided large quantities of Lower Carboniferous ‘Westleigh Limestone’ from central east Devon for later 19th century and 20th century constructions, especially walling (as many other buildings were now being constructed of local brick, made from Upper Carbonifereous mudrocks). The successive arrival of each material can be seen as a sort of ‘stratigraphy’ in some of the cities older surviving buildings and other structures such as the walls – especially where they have been repaired several times, with Permian lavas and breccia in the lowest, and hence oldest parts, but with blocks of Cretaceous Beer and Salcombe Stone above, and sometimes capped by Lower Carboniferous ‘Westleigh Limestone’.

By the 19th century, however, the use of a variety of stones in a construction of status had become more a matter of contemporary taste and decorative style and the Royal Albert Memorial Museum, opened in 1865, provides an excellent example, with at least 12 regionally sourced stone types being used in its construction (as listed in Dove 1994).

This dramatic change from the use of locally sourced to much more distantly sourced stones is widespread in Europe, and typically associated with the industrial revolution from the mid19th century. The arrival of steam machines facilitated the extraction of high quality stones from deeper and deeper quarries, and crucially, railways allowed these materials to be transported further and easier than ever before. Local diversity was definitely being replaced by national and European diversity. A second abrupt change had arisen by the mid-20th century, with increasing globalization created international markets for building materials that have often virtually terminated two millennia of building embedded in local and regional geology. Today, the European market is often dominated by both exotic and everyday stone products from countries such as India, China and Brazil. And even within Europe, local roofing slates, flooring and wall-covering materials have been replaced by materials from countries such as Portugal, Spain and Italy. But this trend had already started earlier, as imperial trades routes bought materials from distant parts of empires back to Europe, and vice-versa, for instance Cornish granite from Bodmin Moor (SW Britain) has been used in constructions in Brussels, Copenhagen, Bombay, (India), Singapur, Gibralter and many other places across the UK and globally (Macadam, 2003).

Products such as these are sold under various commercial names that are often misleading with respect to their intrinsic physical and chemical properties, for instance inferior quality cleaved mudrocks with limited actual resistance to normal weathering, but sold as roofing materials. Certificates and quality control procedures are consequently urgently needed here, not only taking into account existing standards for mechanical properties, but also specific aesthetic and durability parameters that are also important, including in restoration projects, such as sulphate attack resistance, discoloration, etc (Dreesen & Dusar, 2004, Fronteau et al., 2010; Malfilatre et al., 2012, 2014). Such certification and quality assessment is a major goal for the new IUGS Geoheritage commission (Pereira et al 2016).

But the movement of such materials is not one-directional, with some French stones, such as the Sarrancolin marble for instance, now being little used in France but exported to the Middle East as a luxury decorative stone. In addition, the ‘Norwegian national stone’, Larvikite, in widely used in France (and Britain also) as a facing stone for shops, whilst Provencal rudist limestone (fig 13) is used for flooring in prestigious buildings in Iceland such as the headquarters of the main geothermal unit of Nesjavellir and Portuguese and German limestones are widely used for floors and wall facings in England, even within the campus of Plymouth University itself. It seems that there is no more ‘local stones’, as in music, economy and art, these are now ‘world music’, ‘world economy, or world stones’ …

Fig. 13. Paving slabs in Aix-en-Provence TGV station – a local Cretaceous rudist limestone (the rudists are 5-10 cm long) © P. De Wever

A very good example of the expansion of uses for a stone is illustrated by the 'Pierre de Caen' from Normandy. This white limestone of Bathonian (Middle Jurassic) age is famous as it is clear when just extracted, but becomes white and harder in contact with air. It has been used since prehistoric times and famous early usages include the Merovingian sarcophagus (VIIth century) and extensive use by William the Conqueror (11th century; Dugué et al., 2010). The Pierre de Caen was the original 'pierre de taille', a term that, over time, expanded to include other natural stones with a similar coloration and ease of carving (Pereira and Marker, 2016). Originally, the stone was extracted from area of the city of Caen, but as it was more and more widely used, quarries were installed on the flanks of the valley around the town (Juignet P., 1992). William wanted to use the stone to build his English capital, but it was much later that it was most extensive used in London, including for the Tower and London bridges, the parliament building, Westminster Abbey as well as constructions in Chichester and Durham. Indeed, until the XIVth century, the Pierre de Caen was almost exclusively used for English constructions (Dujardin, 1993) and some quarries still had English owners during the 19th century. Because of this huge demand, the quarries started to work underground (fig. 14), the workings now extending to more than 300 hectares.

By the end of the 19th century the Pierre de Caen had spread across Europe, with important constructions in Belgium, the Netherlands and Germany – but was also in use much further afield, for instance in Canada (Montreal), the USA (New York) and in the Bermuda's Islands

Fig. 14- Winch used to bring to the surface heavy blocks of Pierre de Caen from underground quarries - note the white colour of the stone © D. Peeters

The history of building of each town is not continuous in time; it is punctuated by periods of war, economic crisis, destruction, restructuring and reorganization (for instance the creation grand boulevards in Paris by Baron Haussmann in 19th century) and periods of recovery, population growth, reconstruction, or even some very specific circumstances. For example, Napoléon named Gaspard de Chabrol, Baron de Volvic, as the prefect of the Seine Department in 1812. And to favour his home country he choose to use an exotic stone for Paris: a lava from the Central Massive, the 'Pierre de Volvic' mentioned previously, for several parts of the capital such as the Pantheon place and some paved roadways and curbstones). In this way, significant changes can occur in the relationship between building periods and styles, and the associated use of building materials.

Heritage stones and education

Although some specialists consider that the use of the term 'geoheritage' should be restricted to sites exposing on demonstrating geological materials and processes (De Wever et al., 2014), we believe that including buildings, monuments and other man-made features *constructed* of geological materials is entirely consistent with the concept of geodiversity and crucially, may also be used for the promotion of geological values, contributing to the dissemination of knowledge about the Earth sciences and raising public awareness (see also Palacio-Prieto 2015). We are convinced that it is possible to demonstrate to a large audience that a strong connection exists between their everyday life and geology and, moreover, that this science can be understandable to most people and not just specialists.

One of the most efficient ways to achieve such aims is through outreach. Many different methods are possible such as public conferences, illustrated books, newspapers and formal education. However, a well-established and effective way of raising awareness is through the production of self-guided walks or 'trails' using guide books and leaflets – although increasingly, downloadable internet sources and 'Apps' are also now being used. The goal of such media is not only to show how geological materials have been used through time – and hence their cultural context and significance – but also to raise awareness of the geological processes that formed the materials in the first place, that is their intrinsic, *geological* story. These guides reveal to both local residents and the richness of building stones in common use, as well as the link to famous buildings which are part of a common, human heritage and our culture. Increasingly, the most cultural significant of these stones have been proposed as candidates for nomination as Global Heritage Stone Resources – building stones that have a cultural history encompassing a significant time period and have been utilized in significant works, either in buildings, sculpture or more utilitarian applications (Cooper et al., 2013). Such guides can also be invaluable for school education, as resources for field visits to *in-situ* geological localities becomes scares or health and safety regulations make such visits difficult or (virtually) impossible.

The concept of geological trails focused on building stones is not a new one, but the sophistication and quality of guides has dramatically increased in recent years – so has availability through web applications. In the UK, the concept of guides to building stones first probably became popular in the 1990s, with production often being led by local voluntary organisations, such as RIGS groups (Regionally Important Geological sites), some of which even selected key buildings as geoconservation 'sites' to be protected through spatial planning regulations. Of particular note is a series of 'Thematic Trails', focused on English cities, including Exeter as noted above, which applied an analytical framework for identifying target audiences and encouraging active participation – typically with educational aims - and not just passive observance (as described by Keene, 1996). Many UK cities and towns have ultimately received one or more guides of different technical levels, some specifically designed with school-level education in mind. A common problem, however, is associated with production and printing costs and distribution – ultimately meaning that once a limited print-run was exhausted, the guide was no longer available in any form. Some, however, are now available for download, but the private printing costs can be significant for appropriately 'attractive' guides produced with full color illustrations - and the size of most hand-held electronic devices is simply not large enough (or bright enough in out-door conditions) for even the simplest geological illustrations to be understood by a non-specialist user. In reality, there is still no more attractive (i.e. to a general public) or practical alternative to a well-produced and widely available *printed* guide.

In France some geological visits were organized in the late 1980 by Pr. Maurice Mattauer in the town of Montpellier and since 1990, around establishments which are visited by public for scientific exhibitions such as the *Cité des Sciences* in Paris by Christiane Sabouraud in charge of the geological sciences in this institution and then the *Palais de la Découverte*, in Paris. To allow the public to keep a memory of the visit a picture (fig. 15) was distributed were the different kinds of stones used in the building were represented by colors.

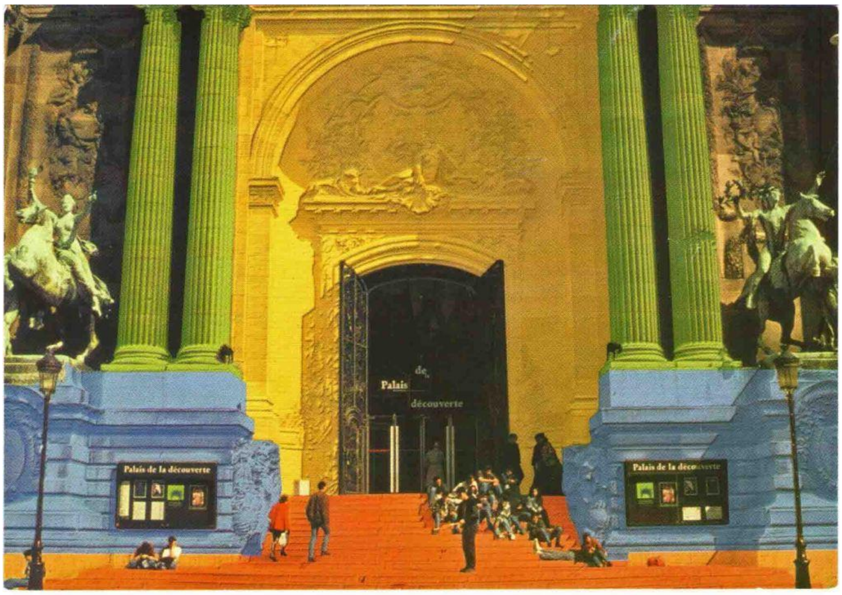

Figure 15
Post card of the entrance of the *Palais de la Découverte* with colours differentiating the stones
red-orange (stairs) : Upper Eocene lacustrine limestone
orange : fossiliferous shallow water limestone, mid Jurassic
yellow : Mid Eocene (Lutetain) miliolids limestone
blue : crinoidic limestone, upper Jurassic
green : oolothic limestones , middle Jurassic limestones © A. Blanc

With this objective in mind the Société Géologique de France and the Muséum National d'Histoire Naturelle launched a national collection of small booklets in France entitled '*Balades géologiques*' ("geological walks"). The guides cover different towns and cities, and occasionally specific places such as the UNESCO building or particular districts within Paris (fig. 16). One of these districts is the "*La Défense*" area, a major business district within the Paris Metropolitan Area and of the Île-de-France region (Baudin, 2015). This district is characterized by high-rise architecture (fig. 17), and provided an interesting challenge to inspire people working there about geology, despite it not being their reason for being present. This collection is now recognized by the Internal Union of Geological Sciences (IUGS) and by UNESCO.

As an example of the content of the guides, two stops in the *La Défense* business district are presented below (taken from Baudin 2015):

Figure 16: Three examples of the '*Balades géologiques'* series focused on Paris- The booklet for Etampes (Billet et al., 2008) was the first published and more than 8000 copies were printed. The second booklet (De Wever et al., 2015b) was prepared for the 70th anniversary of UNESCO. The third examines the La Defense business district (Baudin, 2015).

"Stop 12 - A woman's face set in stone"

"Sitting slightly above the Mastaba, we find a mosaic by Fabio Rieti which can only be appreciated from above (Fig. 17). It shows a woman's face in a rapakivi granite oval frame, resembling a huge mirror. Three shades of marble stone were used to trace the woman's features, hair and the reflection in the mirror, with a few blue fragments used for her eyes (Fig. 17). Red fine-grained limestone is used for her skin. This is a reef limestone from the Ardennes, dating from the Devonian age (380 million years ago). If we look closely, we can see numerous traces of white coral and fractures filled with calcite. Pieces of the same marble, but darker red with white veins, were used for the mouth and hair. White Carrara marble is used to depict the mirror's reflections. The green stone used to outline the hair is a variety of serpentine, thus named because of its color that varies from dark green to black and its mottled appearance that looks like snake skin. It is a magmatic rock called peridotite, formed in the middle of an ocean and altered by water flowing in the vicinity of the magmatic chamber. The whitish veins are where pressurised hot fluids flowed, leading to the formation of new calcium-rich minerals. The rock then formed outcrops after tectonic movements. In France, serpentine massifs are found in the Alps, the Pyrenees and the Massif Central."

Figure 17 – Above: The Face, a work by Fabio Rieti, can only be seen from above. (© Defense-92). Below: Three different marbles trace the woman's features. The red is of Devonian age from the Ardennes; the white from Carrara in Italy; the green is a variety of serpentine. The marble strips are 4 to 5 cm wide. (c) F.Baudin

“Stop 13 - A Comblanchien limestone ramp”

“Now head back towards the Quatre Temps shopping centre. In front of the Courbevoie entrance, there is a ramp and a small surrounding wall, built from greyish beige fine-grained limestone, with a series of pinkish marks and fossil remains (Fig. 18). This is Comblanchien limestone, named after a town between Dijon and Beaune in Burgundy. The limestone was deposited 155 million years ago during the Middle Jurassic, while the Paris Basin was covered by a carbonate shelf, resembling the present-day Bahamas. The Comblanchien limestone was therefore deposited in a shallow tropical lagoon environment. The fossils we can see include fragments of coral and lamellibranch shells; the fact that their two valves are still connected confirms that the environment was relatively calm. The pink-colored marks are secondary transformations (Fig. 18). This limestone is famous in France as many buildings have it for their roofs (Orly airport, Lyon train station in Paris, University of Dijon etc.) and also overseas (Saint-Louis Union Station, USA, Hiroshima Prince Hotel in Kobe, Japan etc.).”
roofs

Figure 18 – (left) One of the ramps leading to the Quatre Temps shopping centre, built from Comblanchien limestone from Burgundy. (Right) Comblanchien limestone often has pink veins. These are iron oxides that recrystallized after deposit. Fossils, including the 5 cm long mollusc shell are also present.

Conclusion

Geology is often considered to be a discipline restricted to specialists, namely geologists, and the amount of touristic information based on the physical aspects of environments is often limited, including in connection with types of stone, geomorphological evolution of the landscape and the relationships of both with the history of local communities. A contributing factor to this deficit, can be a lack of systematic programmes for registering (i.e. ‘inventorying’) national geological heritage, a process which is essential for identifying geosites not only of scientific value, but also of potential touristic significance (although this deficiency is on the way to being addressed in France; De Wever *et al*. 2015, Egoroff *et al*. 2016). Another reason for the deficiency of geoinformation is the almost total ignorance of a general public about geology, which makes it difficult to implement programs related to the conservation of natural landscapes and hence they are often relegated to a low priority.

It is argued that geotourism should include aspects of built heritage or urban geotourism since many historical monuments and buildings consist of many types of different stones, just as there are many notable outcrops of rocks within cities and towns. These sites can help promote geoheritage within cities from both an educational and geoconservation perspective, through geological trails linking sites. Nevertheless, it is important to consider that, due to their accessibility, urban geosites can offer a great potential for promoting geotourism, with the integration of historical and artistic aspects of the city showing that geology is truly a part of a human life and culture. Today, urban geotourism can be considered to be one of the most effective ways to acquaint people with geology, promoting and understanding, i.e. how to read the occupation of urban space and the constraints imposed by the physical environment, including the settlement of the city in the geological terrain and the use of geological materials in its construction.

The ‘*Balades géologiques’* booklets (fig. 16, 19), demonstrate the relationships between local stones (geoheritage), their physical properties and their different uses throughout France (e.g. waterproof at base, used in roof construction, porous on the sides, easy or difficult to sculpt ...). Besides these technical aspects, we have shown how some elements reveal their environmental conditions of formation. In addition, when some historical, social or architectural peculiarities exist, we emphasise these elements, showing that stones are associated with human life. These booklets are generally associated with guided tours and they can act to systematically raise the awareness of eye-opener for the public. To improve this outreach, some ‘balades’ are also available on applications (‘Apps’) for mobile phones (Egoroff *et al.* 2014). This collection was launched in 2008 and by mid 2016, around 30 had been published for different towns across France and they have proved to be very popular. A positive sign was received by the end of last year.

Although geological guides to towns and cities have been being widely produced by geological and educational groups over the last 30 years or so, it is not until relatively recently, that their touristic and general educational potential has been grasped by administrations and decision makers. As a result there are now professionally produced and promoted building stone itinerary guides for many several European cities, many designed as tools for outreach activities, such as the Stone Town Guide for Helsinki and the Stone Town Guide for Kotka, both available from the website of the Geological Survey of Finland (http://newprojects.gtk.fi/ENPI/results/history/city_guides.html**)** and the geological heritage guide to Segovia in Spain (Díez Herrero and Vegas Salamanca, 2011), published by the City’s council and widely available in touristic shops

The IUGS Heritage Stone initiative [http://globalheritagestone.com] is also important in this context, as its scientific focus helps spread scientific information among stakeholders dealing with construction and restoration. Many different stones from around the world have already been proposed as GHSRs, and their intrinsic characteristics published, crucially providing advice on their proper use for new construction and restoration. Some of the stones mentioned in this paper are already on that interim list (www.globalheritagestone.com), and designation as Heritage stones. Other natural stones, such as those used in France for heritage buildings, will be presented for inclusion in this important list in terms of promotion them from a geoheritage perspective besides the books already published (Blanc, 1996, Collectif, 1998) .

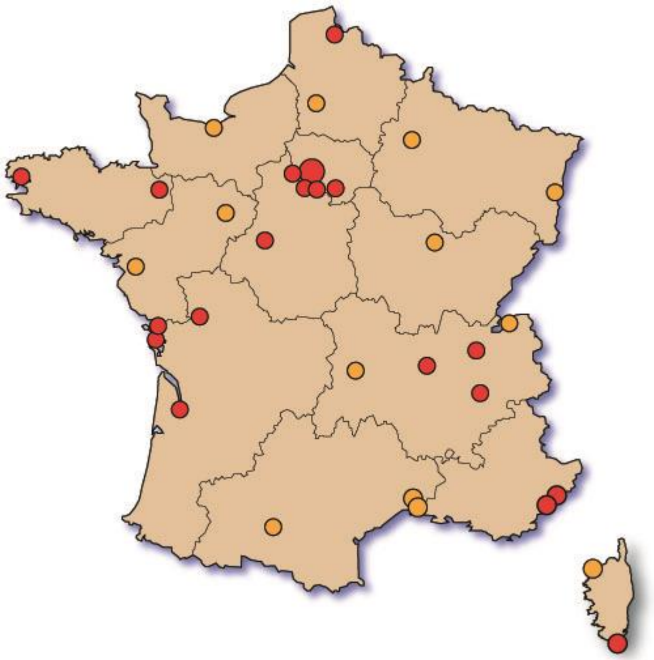

Figure 19 –Map of the 33 available booklets in the ‘Balades’ series: Red dots = published booklets; Orange dots: booklets in preparation.

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Acknowledgements

Two anonymous reviewers helped in improving a previous version of the manuscript. Thanks to Alexandre Lethiers for his work on illustrations and to Maryse Aymes. This work was supported by ASM Patrimoine géologique, of the Muséum National d'Histoire Naturelle (Paris). D. Pereira thanks F. Tourneur for the introduction to underground geology in Brussels. This report is a joined contribution among members of the IUGS Geoheritage Task Group and Heritage Stone Task Group. Authors appreciate the continuous support of IUGS to both working groups.